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Original Research

An Integrated Visualization System for Surgical Planning and Guidance Using Image Fusion and an Open MR

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A surgical guidance and visualization system is presented, which uniquely integrates capabilities for data analysis and on-line interventional guidance into the setting of interventional MRI. Various pre-operative scans (T1- and T2-weighted MRI, MR angiography, and functional MRI (fMRI)) are fused and automatically aligned with the operating field of the interventional MR system. Both pre-surgical and intra-operative data may be segmented to generate three-dimensional surface models of key anatomical and functional structures. Models are combined in a three-dimensional scene along with reformatted slices that are driven by a tracked surgical device. Thus, pre-operative data augments interventional imaging to expedite tissue characterization and precise localization and targeting. As the surgery progresses, and anatomical changes subsequently reduce the relevance of pre-operative data, interventional data is refreshed for software navigation in true real time. The system has been applied in 45 neurosurgical cases and found to have beneficial utility for planning and guidance. J. Magn. Reson. Imaging 2001; 13:967–975. © 2001 Wiley-Liss, Inc.

Index terms: neurosurgical planning; image guided surgery; image fusion; 3D visualization; interventional MRI

IMAGE-GUIDED SURGERY SYSTEMS strive to enhance the surgeon's capability to utilize medical imagery to decrease the invasiveness of surgical procedures and increase their accuracy and safety. These systems can be categorized into performing one or more of the following functions: data analysis (2,3,4), surgical planning (2,3,4), surgical guidance (5,6,7,8,9,10), and surgical guidance with intra-operative updates (11,12,13,14). The systems focused on surgical guidance tend to present the surgeon with data that was gathered prior to surgery, track surgical instruments within the operating field, and render the tracked devices along with the data. For more difficult surgeries, it is beneficial to present the surgeon with not just one diagnostic scan, but with an array of information derived from fusing data sets with information on morphology, cortical function, and metabolic activity. These varied data sets are acquired in different coordinate systems and need to be aligned, or registered, to a common framework for surgical planning before that framework is in turn registered to the patient for surgical guidance. The latter registration allows the surgeon to establish a correspondence between the patient lying on the operating table and the images rendered on a nearby computer screen.

The major shortcoming of image guided surgery systems is that the use of pre-surgically acquired data does not account for intra-operative changes in brain morphology. The systems with intra-operative updates have been introduced to fill that void, but they have fallen short of achieving perfect interactivity and full information disclosure to the surgeon. In particular, the benefits of interventional MRI could be amplified by focusing on five issues: image quality, imaging time, multi-modal fusion, faster localization, and three-dimensional visualization. The need for better image quality arises because some anatomical structures are difficult to distinguish on interventional MR images, but are clearer on conventional, diagnostic MRI that benefits from a higher magnetic field and longer imaging times. Our goal is to provide both in surgery. Imaging time is a critical constraint because in order for surgical guidance to be interactive, images must be acquired quickly enough to be utilized without disrupting or slowing down the procedure. Multi-modal fusion is desirable considering that functional and metabolic data that is acquired pre-operatively could deliver increased benefit if integrated with intra-operative, anatomical information. Faster localization is needed because interventional MR provides the capability of planning approach trajectories by maneuvering a

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